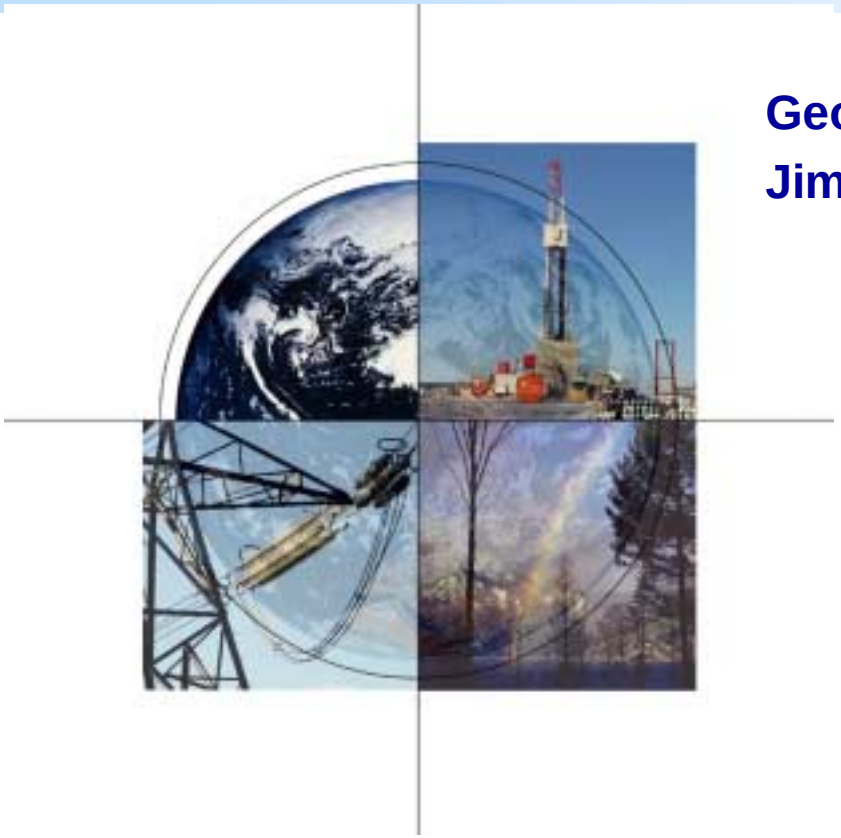
New Methods to Characterize and Control Turbine Combustors



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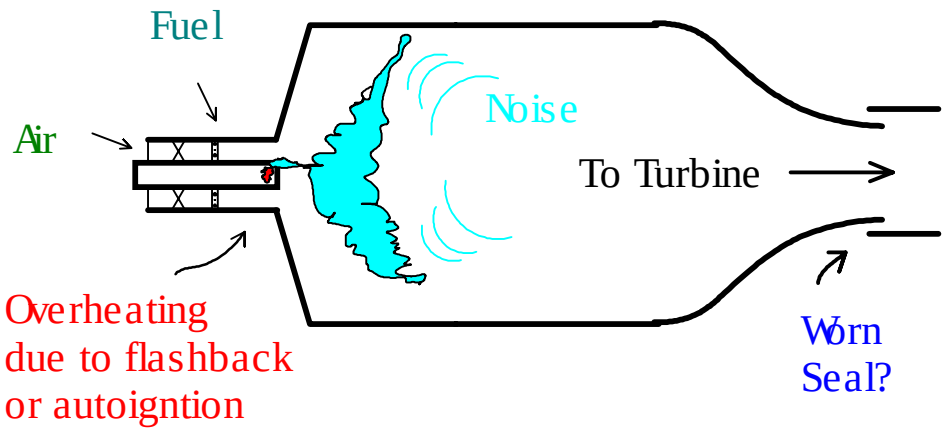
Presented at the
Turbine Power Systems Conference
and
Condition Monitoring Workshop

February 25-27, 2002
Galveston, TX

The National Energy Technology Laboratory

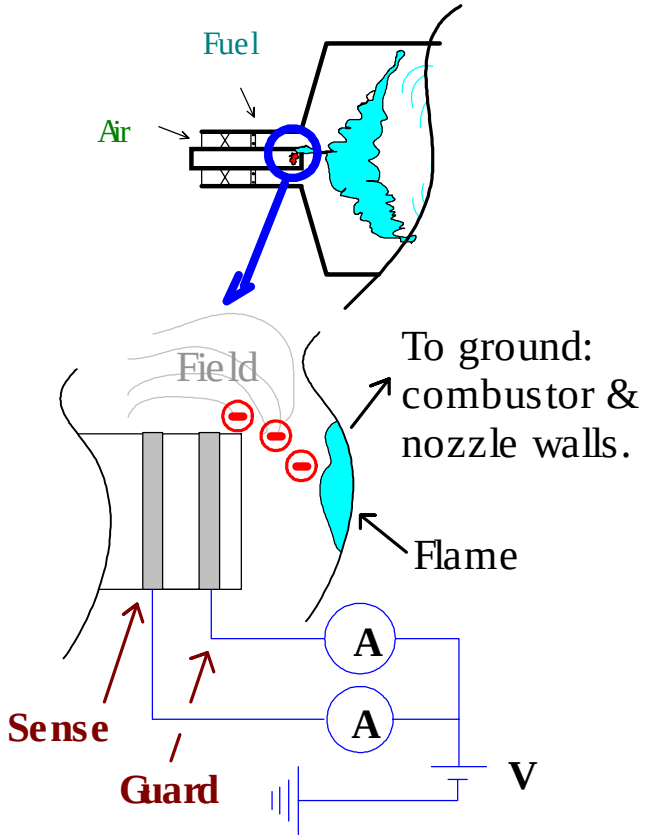
Sensors and Control for Turbine Combustion

- **Address potential malfunctions in combustors**
  - Flashback (upset conditions, worn or broken seals)
  - Auto-ignition (fuel changes)
  - "Vibration" (fuel & ambient changes, worn seals)
- **Use feedback control to *enhance* performance**
  - Accommodate *variable composition* syngas
  - Maintain low-emissions w/o tuning maintenance



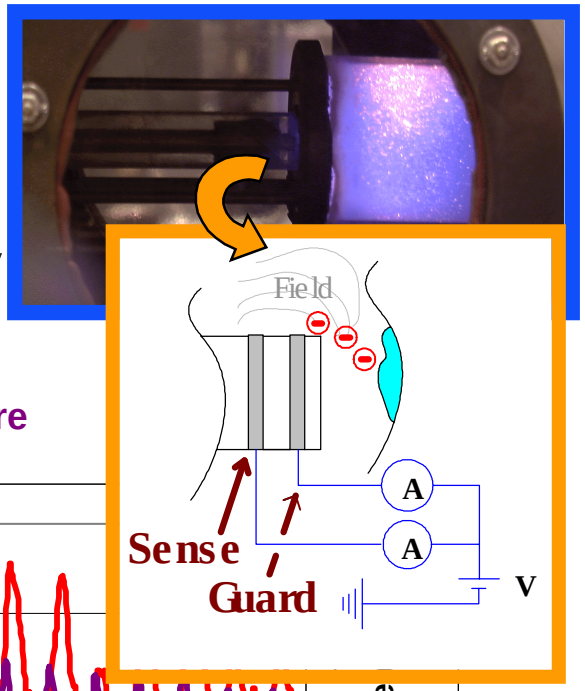
A Low-Cost Sensor from Flame Ionization?

- **Flames are good conductors; lots of ions.**
  - Commercial applications: FID, piston engines, and safety systems.
  - Some physics: electrons especially mobile, will move outside of flame in response to applied fields.
- **Concept: insert equal potential electrodes on the fuel injector.**
  - "Guard" electrode captures mobile ions in the boundary layer.
  - "Sense" electrode detects the flame in the wrong place.

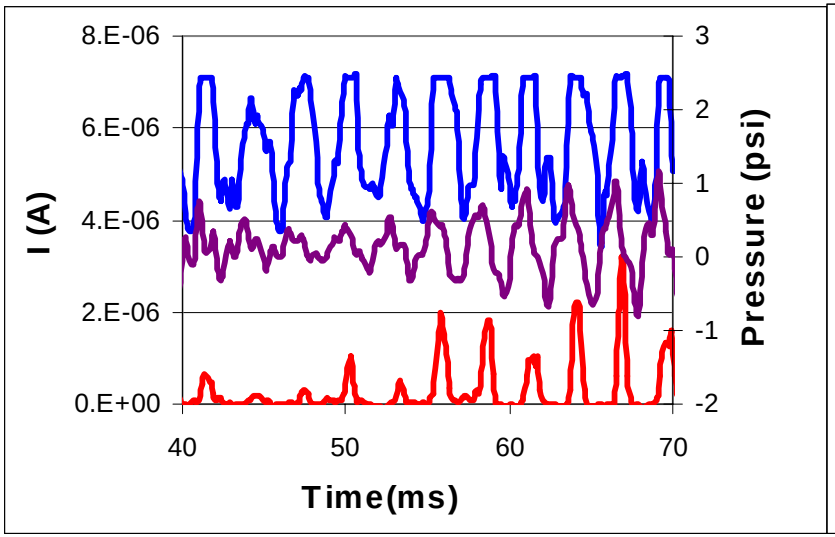


Concept Demonstration

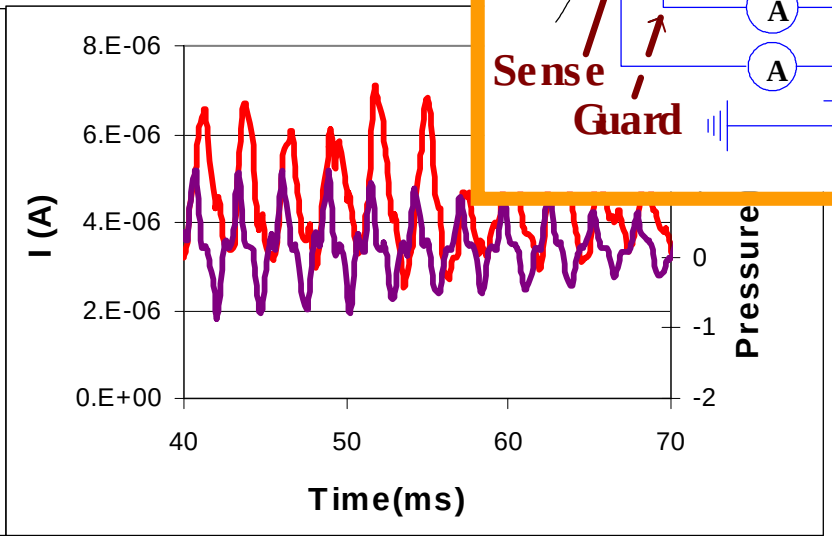
- **Laboratory 7.5cm diameter combustor**
- **Interesting observations**
  - Response to dynamic pressure
  - With versus w/o guard shows charge mobility
  - Offset w/o guard = flame conductivity



---- Guard Current ---- Sense Current ---- Dynamic Pressure



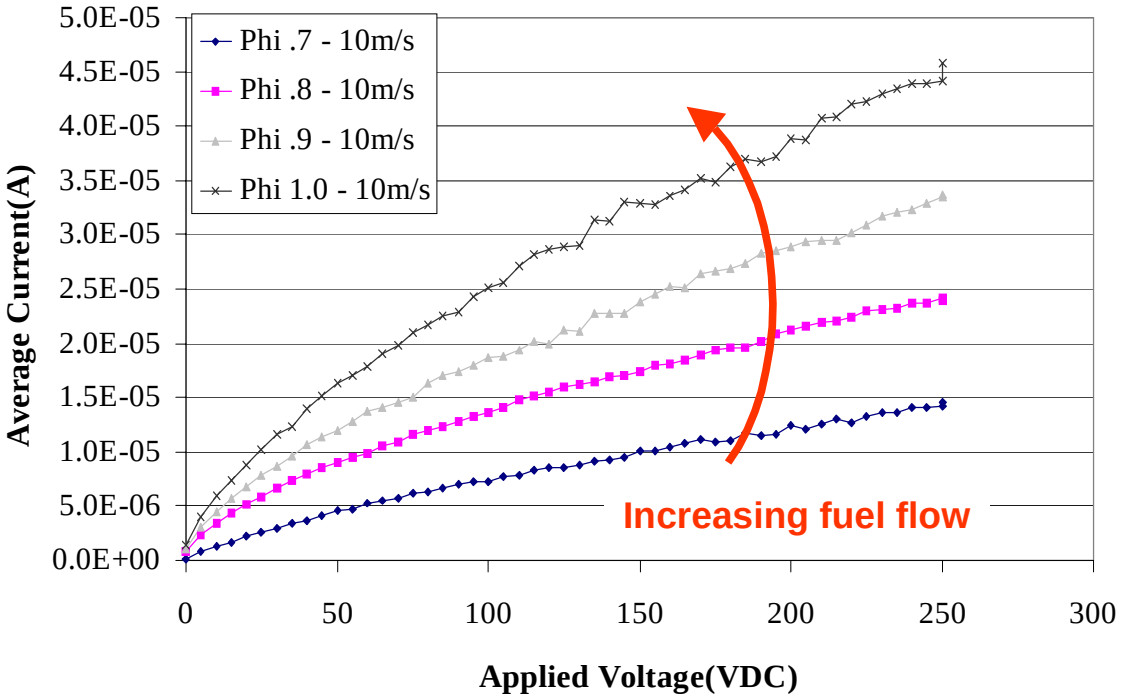
With guard voltage

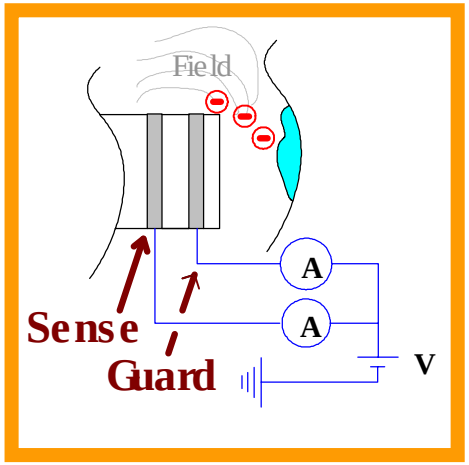


Without guard voltage

Sensing Fuel/Air Ratio

- **Optical methods. OH*, CH* chemiluminescence**
- **CHO* formyl radical ?**
  - Better indicator of heat release (Najm, *et. al.* 1998).
  - CHO^+ is the cited as major species for ion formation.



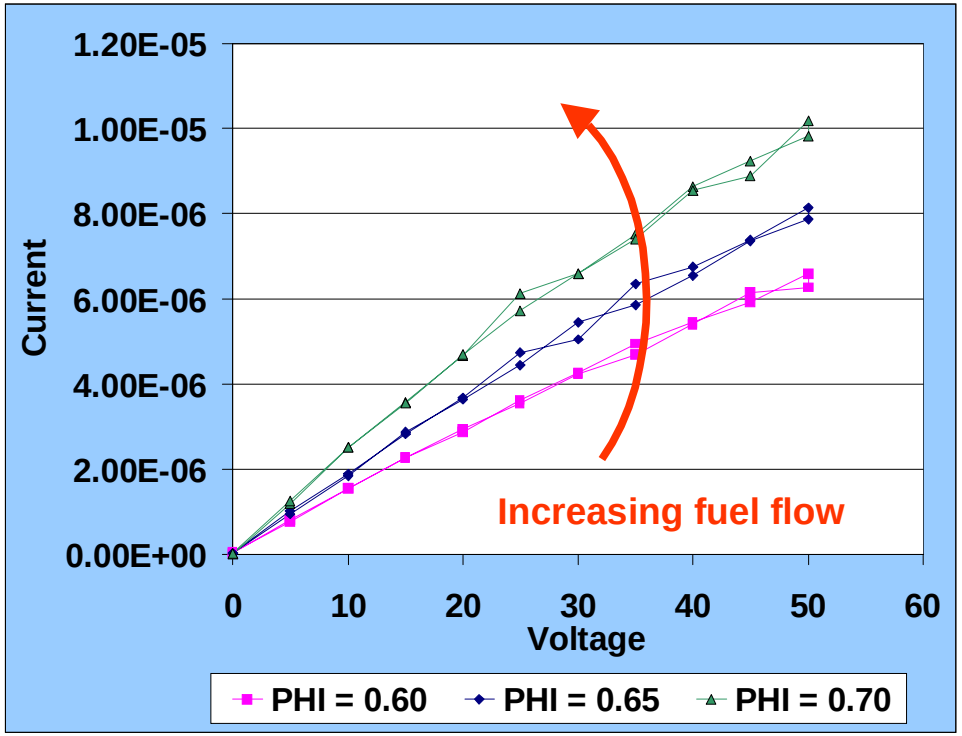


Guard current versus voltage at various fuel/air ratios (Phi)

Similar results from full-scale combustor test

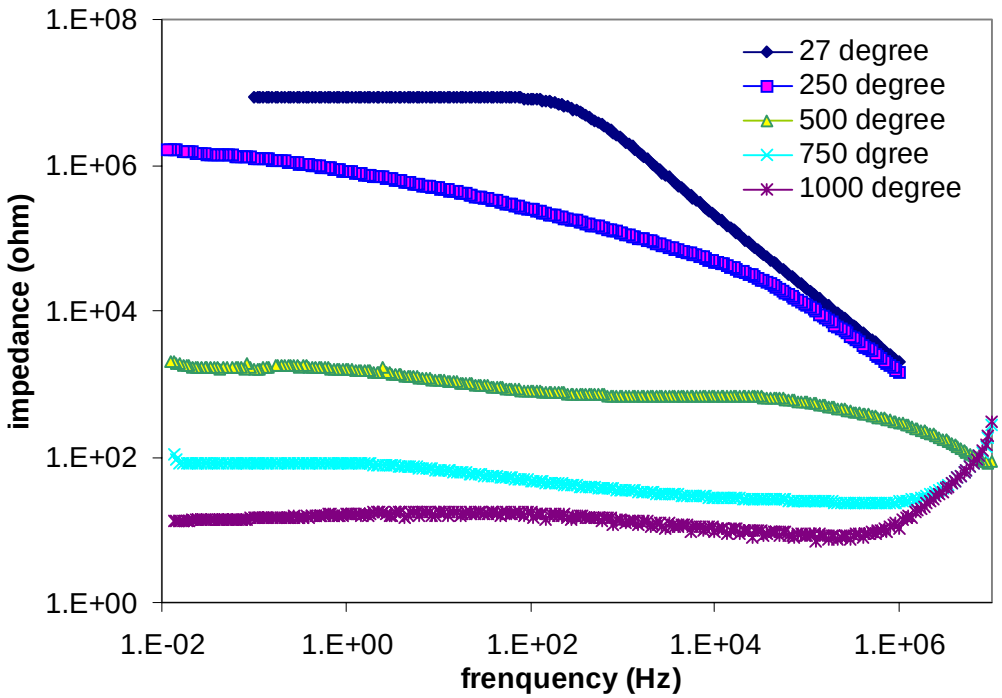
- **NETL dynamic gas turbine combustor.**
  - 10 atmospheres, 590K inlet, ~1kg/s air flow
- **Test of isolated sensor similar to lab scale.**

Isolated Electrode - Tungsten Rod through center of the center-body



Issues for practical application

- **Modern turbine combustors are lined with thermal barrier coatings (TBC).**
  - Measurements of impedance: not a problem
- **Flame anchoring changes complicate current interpretation.**



Measurement of TBC impedance versus AC frequency at temperatures 27C to 1000C (S Mao, U. Pittsburgh)

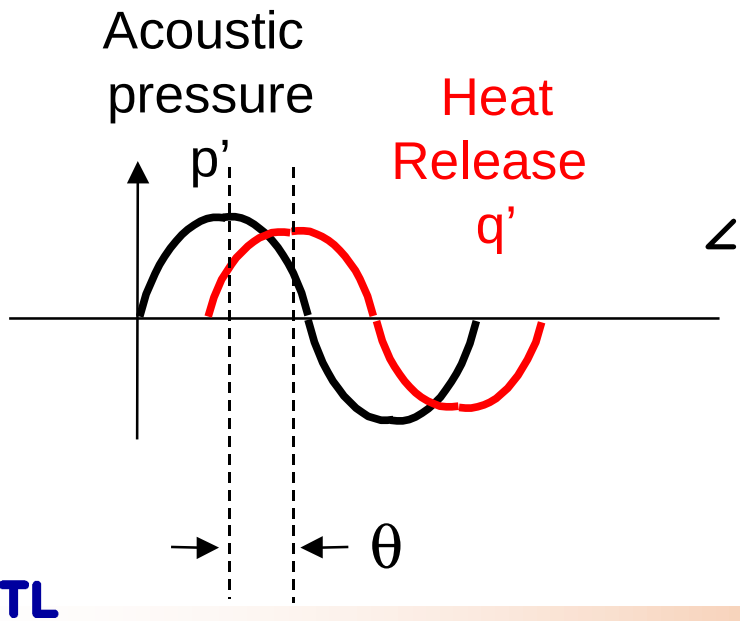
Improving Combustor Reliability

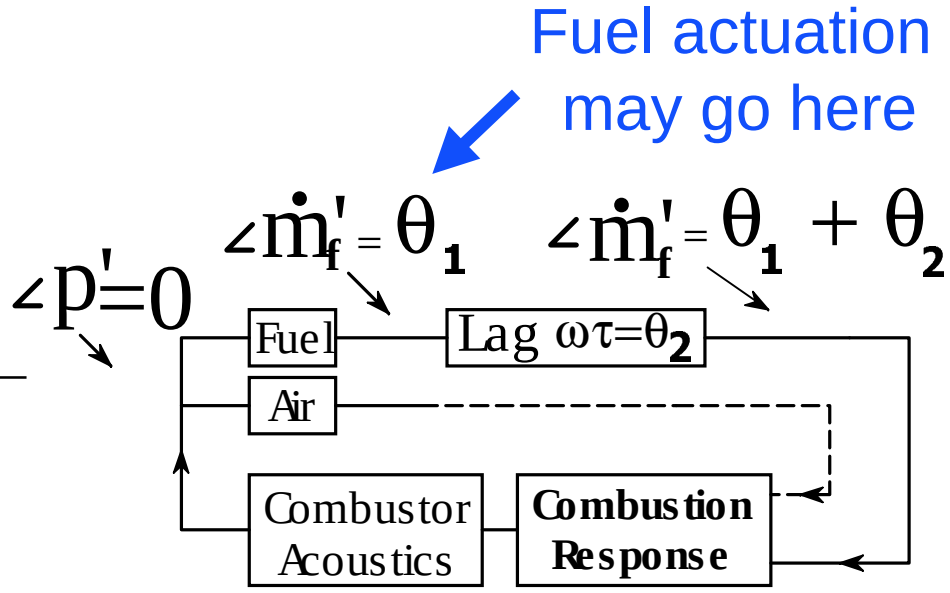
- **Current fleet of low-emission turbines**
  - Combustion dynamics (vibration) limits fuel tolerance.
  - Combustion vibration decreases component life.
- **A problem for coal syngas?**
  - Similar problems in two IGGC start-ups*.
  - Fuel flexibility desired for Vision 21 plants.

* DeBiasi, V. (1999). “Gasification on Track to Turn Problem Fuels into Electric Power and Products” Gas Turbine World, Nov-Dec 1999, pp. 18.

Technical Approach

- **Passive solutions: reduce gain, or change phase (e.g., adjust τ).**
- **Active solutions: can readjust as combustion response changes (fuel type, etc.)**
- **Drawback: actuation is a challenge.**

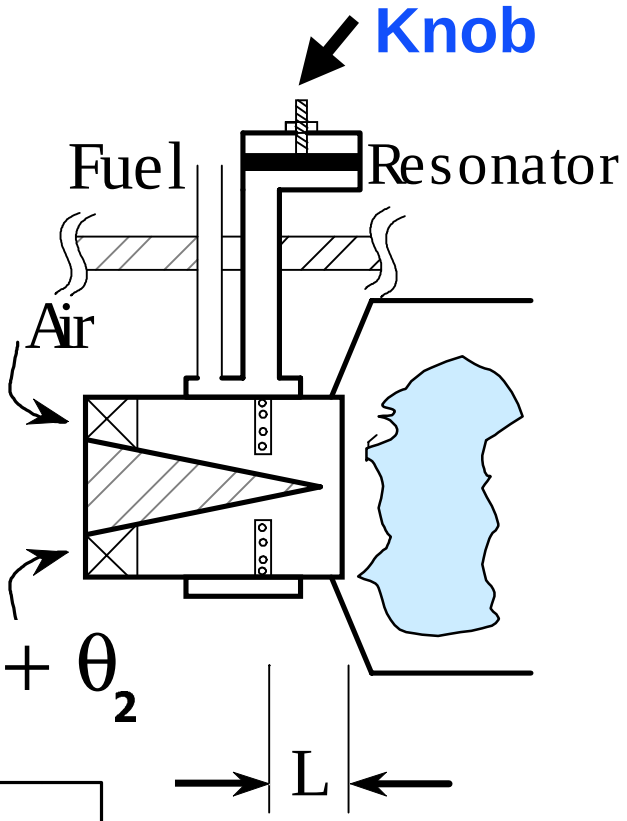


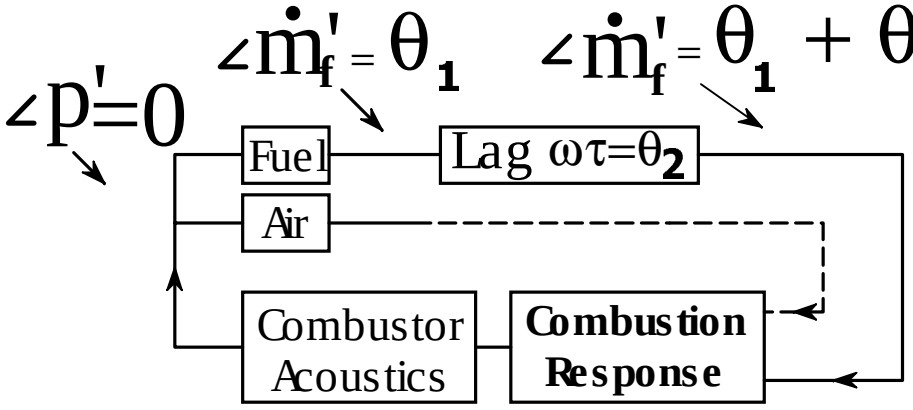


Technical Approach (cont.)

Schematic of Concept

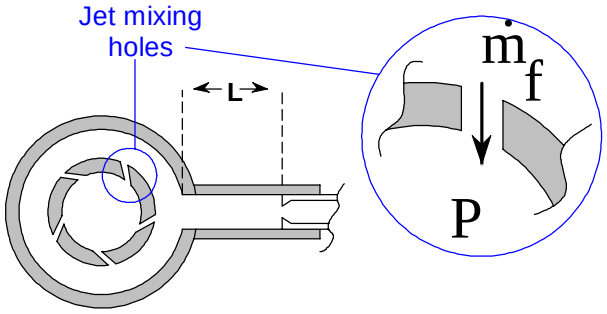
- **Passive time lag adjustments require hardware changes (L).**
- **Some adjustments in dynamic response possible via "knob".**
- **How much adjustment?**

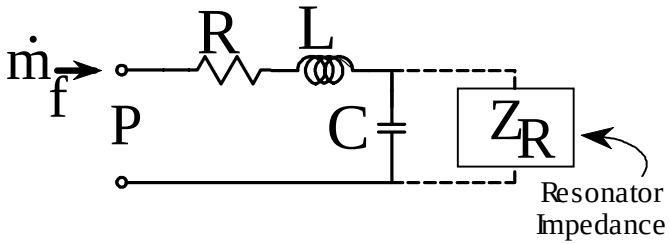


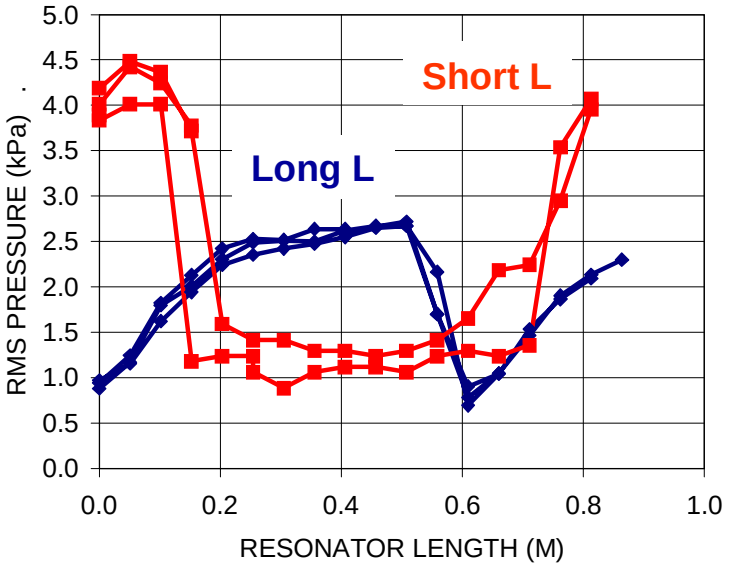


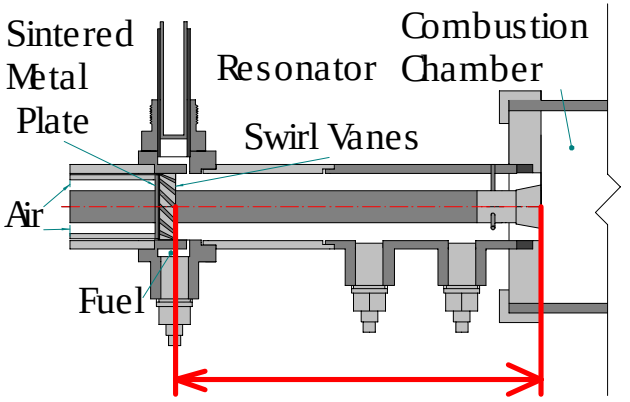
Progress to date

- Characterized the acoustic “adjustment” of practical fuel systems. (see ASME 2001-GT-0038).
- Reported first combustor trials at Advanced Gas Turbines Systems Research Combustion Workshop.





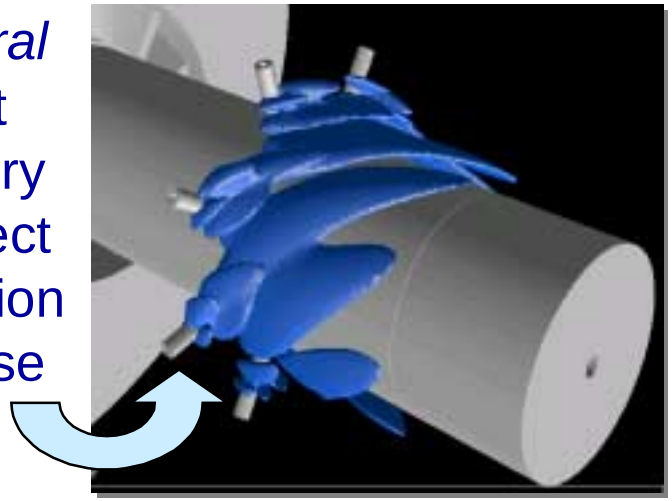




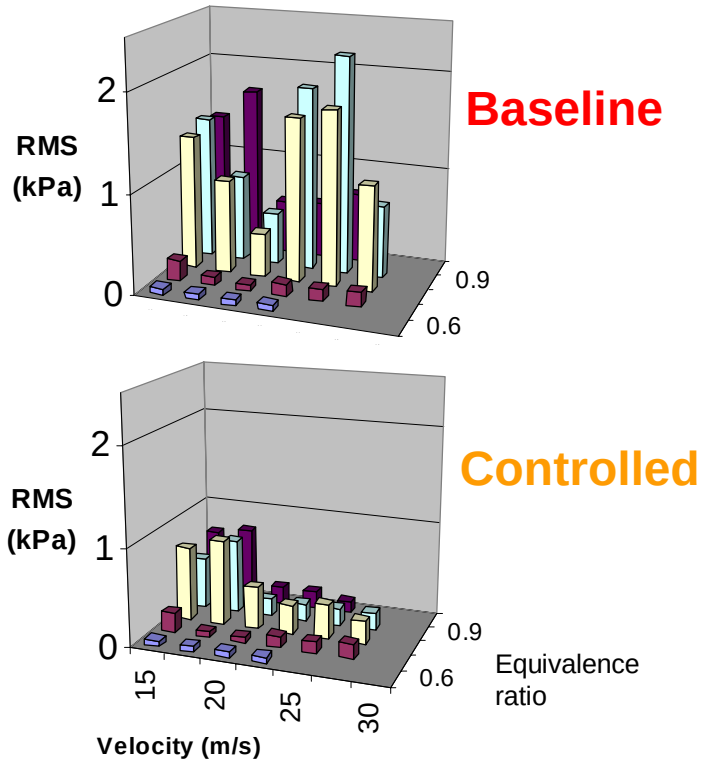
Encouraging results!

- **Very good attenuation potential demonstrated.**
- **Work in progress: evaluate temporal mixing effects to avoid scale-up faux pas.**

Temporal fuel jet trajectory may affect combustion response



Simulated fuel jet trajectory in full-scale premixer



Summary

- **Modern combustors can benefit from sense and control of:**
  - fuel/air ratio changes, flashback
  - dynamics from fuel variations
- **NETL is investigating two concepts:**
  - Use flame ionization for fuel/air ratio, flashback.
  - Passive-active control of combustor dynamics.
- **Work in progress**
  - Flame anchoring effects on ionization signal.
  - Scale-up mixing studies for passive/active control.